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STUDIES OF THE ENVIRONMENT FROM SPACE

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16. Abstract

This review of studies conducted in the United States on the problem of investigating the environment from space, is based on materials of the 21st International Congress on Astronautics, held in West Germany in October 1970.

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STUDIES OF THE ENVIRONMENT FROM SPACE

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Important advances in the field of satellite meteorology have opened great promises for the use of satellites and manned orbital stations for the purpose of comprehensive investigation of the environment, analysis and evaluation of natural resources. The first experience in the combined solution of this type of problem was the effort of a group of coworkers of the Leningrad University and Main Geophysics Observatory, in which cosmonauts V. N. Volkov, B. V. Volynov, A. G. Nikolayev and V. I. Sevast'yanov participated. This project was completed within the scope of the scientific manned space program of "Soyuz-7" and "Soyuz-9." /108*

The report "Spectrophotometric Studies of the Earth from Manned Spaceships," presented by K. Ya. Kondrat'yev at the third symposium of the International Orbital Laboratory, concerns the results of a combined satellite experiment. This experiment, consisting in an extensive program of optical measurement from manned spaceships, airplanes and on the ground, afforded the possibility of studying the use of optical data (spectral brightness coefficients, radiation and radio brightness temperatures, etc.) for distinguishing and identifying natural formations, and also for evaluating the distorting influence of the thickness of the atmosphere on the results of measurements of the brightness of natural formations in various bands of the spectrum from space (the first results of these studies were summarized in an article, published in *Doklady AN SSSR*, Vol. 195, No. 5, 1970).

The United States is presently conducting extensive studies for the purpose of developing methods of remote studies of natural resources on the basis of the data of airborne spectral measurements and is building a satellite which will be launched in 1972. The results of this area of investigation were publicized in a series of reports by American specialists, presented at a meeting of the congress of natural resources. Doctor L. Jaffe, Administrator

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*Numbers in the margin indicate pagination in the foreign text.

of the NASA department of scientific and applied space studies, presented the main report on this topic.

Just comparatively recently only a few specialists envisioned such a need as there is at the present time for detailed information about the state of the environment. It is becoming increasingly clear just how scarce are the existing data on ecosystem dynamics. At the same time such data are extremely important for making decisions involving the use of natural resources, conservation and development of regenerable resources. Therefore it is essential to conduct continuous observations of the state and dynamics of the environment, which can be done only from satellites, even though airborne observations also continue to be important. In fact, airborne studies have demonstrated, for example, the feasibility of forest fire detection on the basis of infrared thermography.

Temperature irregularities that are observed on infrared images can apparently be used for identifying areas of a forest that are infected with diseases and are underwooded because of deficient soil moisture, soil salinization, and insects.

The solution of such problems as evaluation of harvests, detection of plant diseases, etc. are very important for agriculture. Very informative data were obtained on the basis of analysis of photographs taken from the "Apollo-9" spaceship in four wavelength bands. These data were used, for example, for /109
constructing a chart of the distribution of pine forest over an area of 12 million acres in the states of Louisiana, Arkansas and Georgia.

One of the most obvious fields of application of natural resources satellites is mapping of various characteristics of the earth's surface. Seventy percent of existing world maps are inadequate, and the remaining 30% are obsolete. Thus, for example, there is no up to date hydrological map of the United States, and the process of making the last one took about 10 years. Therefore some of the data were obsolete even before the map was completed. With satellites it is possible to obtain fresh information immediately for hydrological and soil maps. The first successful experience in soil mapping has already been gained for the Imperial Valley in California by satellite photography of this region. One satellite photograph can take the place of 3,200 ordinary aerial photographs, at the same time providing much more homogeneous material. The economic effect is such, for example, that in the United States alone a 1% increase of livestock because of more reliable and complete information on pastures, obtained from satellites, will pay all the expenses for completing the corresponding satellite program.

The discovery of new mineral resources, analysis of the ecological and other anomalies are areas of application of natural resources satellites that will provide results of great practical importance. The use of radar makes it possible to probe even the uppermost layer of the earth's crust. The present plans for utilizing various bands of the electromagnetic spectrum (from the ultraviolet to radio wavelengths) for the purpose of studying various natural resources hold out the promise for studying earthquakes, geothermal sources, volcanism, floods, soil erosion and other phenomena.

Hydrological and oceanological investigations are very urgent: tracing of snow and ice zones, evaluation of the thickness of the snow and ice cover, analysis of snow and ice thaw dynamics, topography of the floor and pollution of lakes and other bodies of water, and also of coastal waters, observations of shoreline dynamics, determination of surface temperature and wave action of the ocean, of various biological characteristics (plankton, animal life, etc.) of the top 50 m of the ocean, etc. Development of a natural resources satellite will also make it possible to perform the following: 1) more accurate description and mapping of parameters that characterize the state of ecosystems; 2) expand the capabilities of analyzing the consequences of man's actions on the environment; 3) collect data necessary for adequate planning and economic activities; 4) provide more reliable information about acts of God. The chief advantage of satellite observations is the possibility of collecting systematic (with the required redundance) data for vast territories.

Of primary importance here is development of methods of automatic (computer) analysis of data.

The program for investigating the natural resources of the earth with the aid of satellites, described in reports by American experts (L. Jaffe, W. Scull, F. Langley, L. Farnham and D. Keller), is aimed primarily at the utilization of data obtained from the earth resources technology satellite (ERTS), being built by NASA, and includes the following sections: 1) marine resources and oceanography; 2) water resources; 3) mineral and earth resources; 4) man's environment; 5) cartography.

The requirements on the first ERTS, designed on the basis of the "Nimbus IV" meteorological satellite, consist in obtaining television pictures of territorial areas measuring 180 × 180 km^2 with a three-dimensional resolution of 30-60 m in three bands of the spectrum: 475-575 nm (the blue-green: detection of underwater objects); 580-680 nm (the red: differentiation of forms and types of vegetation, including agricultural, γ-distribution of landscape features); 690-830 nm (the infrared: mapping of the shoreline, evaluation of the distribution of the relative soil humidity and density of the vegetation cover).

The satellite will also be equipped with a four-channel scanning radiometer (on the wavelengths 0.5-0.6, 0.6-0.7, 0.7-0.8, 0.8-1.1 μ), which will obtain data for quantitative analysis (in contrast to qualitative analysis of television pictures) and computer processing. Each scan line will contain 3,000 elements, which at a line length (at the level of the earth's surface) of 180 km will provide a spatial resolution of about 60 m. A five-channel radiometer (with the 10.4-12.6 μ band added) will be built for the ERTS-B satellite.

Each television camera will produce 60 pictures a day. The scanning radiometer will produce images in the form of continuous 180 km wide bands, which in a day's time is equivalent (in terms of area) to 240 television pictures. A special research office will be organized in July 1969 at the Houston Manned Spaceflight Center for receiving and processing all these data. The ERTS satellite will be placed in a circular polar (angle of inclination 99.088°), solar synchronous orbit at an altitude of approximately 900 km to /110
give it a guaranteed service life of about 1 year. The satellite will weigh 740 kg. The accuracy of three-dimensional orientation in space (relative to the earth's surface) should be better than 0.7°. The orbital characteristics of the satellite and the field of view of the equipment will ensure complete coverage every 18 days of the territorial United States with pictures related to the same local time. Reception of data from the satellite and control of

its operation will be accomplished at three points: the Goddard Spaceflight Center, Corpus Christi, Texas and Fairbanks, Alaska.

One of the chief problems of interpretation of ERTS data consists in soil analysis for classification (for engineering purposes in particular), detection and monitoring of salinization dynamics, analysis of the conditions of land use and soil pollution, monitoring of national parks, etc.

It was mentioned above that the corresponding techniques have already been developed on the basis of the utilization of photographs obtained from "Apollo-6" and "Apollo-9." It is noteworthy in this connection that the scientific equipment of "Apollo-9" included four Hasselblad cameras, which were used for photographing the earth in the following spectral bands: 470-610, 510-890, 590-715 nm. The photographs obtained from the cameras, with a field of view of 50°, cover square land areas about 180 km on a side. The positives, blown up to 22.5 × 22.5 cm, correspond approximately to a cartographic scale of 1:800,000, which is comparable to the three-dimensional resolution that is planned for the natural resources satellite (1:500,000). Aerial photography was done simultaneously at altitudes of 10-12 km, which produced photographs covering a land area 27 km on a side (the scale is 1:250,000 and the resolution is about 3 m). For comparison of the data these photographs were converted to the scale of the photographs taken from "Apollo-9."

In order to study the feasibility of the practical application of satellite data the prospects of multipurpose application of such data were investigated for two agencies, the Tennessee Valley Authority and the Desert Research Institute. Representatives of these agencies assert that each of them can use photographic data for many purposes, including the following: land use mapping, description of the condition of forests and other forms of vegetation, monitoring of air and water pollution, etc.

Land use mapping is aimed at the solution of such problems as the choice of the best areas for construction, determination of potential sources of water pollution, refinement of topographic maps, etc. The need for systematic updating of data for large territories (every 5 years for urban areas, for example), determines the advisability of using satellite observation. The same is true in regard to forest observations (aerial photography does not provide sufficiently real-time data).

The characteristics of the spatial distribution of playa are very important for investigation of the hydrologic cycle of arid zones. Two methods were used for analyzing photographs from "Apollo-9" and aerial photographs: 1) interpretation of images in individual spectral bands; 2) investigation of the correlation relations of the brightnesses of the images for two or more spectral bands. Analysis of the photographs led to the conclusion that they contain a great deal of information from the standpoint of the solution of the above-mentioned problems. Thus, for example, by studying the texture and tone of a picture it is possible to distinguish up to 10 different classes of land utilization.

Utilization of the specific features of the interpretation of photographs, taken in different bands of the spectrum (for example, the infrared band of 680-890 nm is most effective for distinguishing soil humidity irregularities) is of great importance. Color infrared pictures (510-890 nm) are most informative because of the greater capacity of the human eye to distinguish colors than gray tones on black and white photographs. It should be pointed out, however, that the use of automation and photographic enhancement instead of manual analysis may alter the results of analysis.

The development of methods of interpreting satellite data on the environment through the optimum combination of automatic (computer) and manual processing should be considered to be one of the most urgent problems of the day. Up until now mostly systems that display data in picture form have been used for remote indication. This form of data display is most suitable from the standpoint of analysis of a large volume of data, characterizing three--dimensional fields, by man, but when the future information explosion is taken into consideration it becomes obvious that pictures will no longer be the predominant form of data display.

However, the conversion to high-speed computer processing will be delayed by its lack of development in application to specific problems, and for this reason the pictorial display of data will continue to be important for the next few years.

Automatic data analysis within the framework of the taxonomic approach, in which the computer performs the task of recognition of results in relation to a fixed area, by classifying them as belonging to one of certain categories, is the simplest and most accessible method of automatic analysis. The first thing that must be done here is identification, and then classification of an object. An example of the solution of this type of problem based on utilization of data on the spectra of reflection of natural formations showed that the basis of classification in this case is construction of multidimensional vectors that characterize the variety of brightnesses that correspond to various natural formations. It was shown, for example, that on the basis of brightness data in the 0.40-0.44, 0.62-0.66, 0.80-1.0 μ ranges it is possible to distinguish nine classes of vegetation (corn, soybeans, alfalfa, rye, etc.) and bare soil with a reliability of about 90%. The analogous method of recognition and classification of geometric shapes was successfully tested on examples of pictures of the lunar surface and of the cloud cover of the earth. It may be very important in all cases to use data not only on the spectra, but also on the time variability of the various parameters (for example, spectral brightness of natural formations). /111

The important feature of research being conducted in the United States for the purpose of developing the methods of remote monitoring of the environment is the very extensive application of flying laboratories for simulating satellite experiments. Thus, for example, NASA has a research plane with an altitude ceiling of about 20 km, aboard which are installed multizone cameras for photographing ground formations in various bands of the spectrum, a scanning infrared radiometer for taking thermal pictures of the earth's surface, several spectrometers and radiometers for various bands of the spectrum. In this connection great importance is attached to the choice of test areas, which are analyzed in detail with the aid of ground systems and which are then used as standards for the development of remote indication methods.

One of the most important aspects of the American natural resources study program is the manned orbital station "Skylab," which will be launched in late 1972. The orbiting laboratory will be equipped for this purpose with six cameras, infrared spectrometer, 10-channel scanning radiometer, radar scatterometer, operating on a frequency of 13.4 GHz, radar altimeter operating on 9.4 GHz, and microwave radiometer (1.4 GHz). Part of the spectral bands of the scanning radiometer is matched with parts of the spectral sensitivity of the television cameras and scanning radiometer of the ERTS satellite, which will permit correct comparison of the data from the orbital laboratory and the natural resources satellite.

"Skylab" will be placed in a circular orbit with an angle of inclination of 50° to the equatorial plane, at an altitude of about 420 km without the crew. There will be three crew members, who will be launched several days later and will spend 28 days in orbit. Future "Skylabs" will function for 90 days and their crews will be replaced every 28 days. This will make it possible to return to the earth photographic film and magnetic tape during the course of the experiment and to replenish film reserves. After the completion of the experiment the light filters of the multichannel camera will be returned to earth for control calibration.

It should be pointed out in conclusion that the United States is rapidly expanding the scope of research and development of remote methods of studying the environment and natural resources. Laboratories and institutes on the problem of remote sensing are being organized not only at the major space centers (such as the Goddard Center of NASA), but also at numerous universities. The recently developed commercial firm "Earth Resources Corporation" and many other organizations are conducting extensive studies on this problem. Two new journals, devoted specifically to the problem of remote sensing, are now being published.

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